STUDIES FOR STUDENTS.

SUPERGLACIAL DRIFT.

I. ALPINE GLACIERS.

Lateral moraines.—On the surface of alpine glaciers, there is sometimes an abundance of stony material which takes the form of lateral moraines. The material composing these moraines is derived principally from the slopes above the ice. In its acquisition, the ice is for the most part passive. Alpine glaciers occupy the bottoms of valleys. So far as general topography is concerned, the valley in which a glacier lies may be said to have an ice bottom. From the slopes of the ice-bottomed valley, rock masses, large and small, descend. They may be loosened by the expansion and contraction due to rapid changes of temperature, by the wedge-work of ice forming in the crevices of the rock, or by the growth of roots in the same position. Once loosened, the blocks of rock begin their journey of descent. This may be accomplished rapidly or slowly, depending upon the steepness of the slopes, and other local conditions. Descending the slopes, the loose masses of rock may reach the bottom of the valley, that is, the surface of the glacier. Avalanches which sometimes descend the steep slopes of valleys, are likely to carry down considerable quantities of stony or earthy material. Where avalanches reach the surface of glaciers, the stony material they bear is deposited on the glacier near its lateral margin. A similar result may be effected by landslides. Locally the amount of material carried down by avalanches and landslides may be considerable but on the whole it is not great. The occasional torrents which come into existence during rain storms, or during the season when the snow of the higher mountains is being rapidly melted, descending from the slopes above to the ice below, carry larger or smaller quantities of rock material.

By any or all of these processes, stony or earthy material may descend into a valley which has no lgacier. It may there accumulate at the base of the slope, or it may be carried away by waters coursing through the valley. It may descend into a glacier valley below the end of the ice, when its fate is the same. If it descend into a valley above, but near the end of a glacier, it may fail to reach the surface of the ice, since near the lower end of a glacier, where melting is rapid, the ice often fails to fit snugly against the bounding slopes of rock. Under these circumstances, material descending from the slopes above is liable to fall between the glacier and the valley wall. It is only where the glacier fits snugly against the sides of its valley, that material descending from the slopes can reach its surface so as to contribute to a lateral moraine. In general, an alpine glacier fits snugly against its valley walls in its upper stretches only, and it is here, therefore, that lateral moraine material is most likely to be acquired in quantity, by the processes indicated.

It will be readily seen that steep slopes above the surface of a glacier favor the accumulation of moraine *débris* upon it. While expansion and contraction due to changes of temperature, and while freezing of water in rock crevices, need not be more effective on steep slopes than on gentle ones at the outset, material once loosened will be much more likely to travel down steep slopes than down gentle ones. Steep slopes, therefore, will be more likely to lose such incoherent material as develops upon them, and so be kept bare, while the gentler slopes will be more likely to retain the disrupted and disintegrated material to which they have given rise. On the gentler slopes, therefore, the rock surface will ultimately come to be protected against changes of temperature and other disrupting surface influences, by its mantle of unremoved débris. Thus it comes about that in the long course of time steep slopes above glaciers will contribute much more débris, than gentle ones for the making of lateral moraines.

Beyond a certain point, steepness of slope would not in all ways favor the development of lateral moraines. Beyond a

certain point, steepness of slope does not favor avalanches, since snow and ice cannot accumulate in sufficient quantity to produce avalanches on slopes of too high gradient. The degree of slope would affect landslides in a similar way. If a slope be too steep there can be no slide of loose rock and earthy material, since such materials cannot accumulate in sufficient quantity to give rise to a slide. Since landslides and avalanches are at best no more than subordinate sources of lateral moraine material, lateral moraines are most likely to be well developed on those glaciers which are bounded by high mountains with steep slopes. All the drift which gains a superglacial position by any of the processes thus far mentioned, is superglacial from the beginning of its association with the ice.

It is possible that lateral moraine material may reach its position by another process. Where the bed of the ice is rough, it may chance that the lateral portion of the glacier passes over roughnesses of bed of considerable extent. If the lateral margin of the ice passes over elevations which project up into it nearly to its surface, those parts of the ice which pass around any given elevation will presently come together below the same, carrying with them some material from its slopes. Likewise the ice which passes over the summit of the rock prominence may have worn or torn away more or less rock material from its surface. Such material is at first subglacial, with reference to the ice which removes it, but it quickly becomes englacial as the ice moves on. Some of it may be near the upper surface of the ice, after the ice has united below the obstruction. Further down the valley, as a result of melting, the ice surface may be brought down to the level of this englacial material. When this happens, the englacial material becomes superglacial. This superglacial material which has passed through an englacial history may be an additional source of lateral moraine material. Not all superglacial material derived in this manner could enter into a lateral moraine. Only those portions which reach the surface of a glacier near its margins would be so available. It is possible that, above the differentiated alpine glacier, the ice of the snow-field may have passed

over roughnesses of bed in such relations that englacial material there acquired may subsequently reach the surface of the ice in such a position as to be added to the lateral moraine material accumulated from above. This however is probably not an abundant source of lateral moraine material.

From the foregoing it will be seen that lateral moraine material belongs to two distinct classes. The first class, that descending from the mountain slopes above the surface of the ice, is strictly superglacial. This at least is true of all that portion of it which reaches the surface of the ice below the zone of accumulation. That which reaches it within the zone of accumulation may be temporarily buried by the snow of successive winters, until the ice which carries it passes from the zone of accumulation to the zone of wastage. While such material may have a brief englacial history, it still belongs, to all intents and purposes, with the first class of superglacial material. The second class, that which was taken from the summits of prominences which reached well up into the body of the ice, was at first subglacial, but quickly became englacial as the ice closed together beyond the prominence which gave rise to it. After a longer or shorter englacial journey, it became superglacial, as the result of surface ablation. Since the subglacial journey of such material was exceedingly brief in most cases, and the englacial and superglacial journeys doubtless much longer, it may be called englacial-superglacial drift. Englacial-superglacial bowlders should differ from bowlders which have been superglacial throughout their history, in that the former should show more evidence of wear. This might be inflicted both during their brief subglacial journey, and during their more protracted englacial history.

Medial moraines.—Wherever two mountain glaciers bearing lateral moraines unite, the lateral moraines belonging to the two margins which coalesce give rise to a medial moraine. Such a medial moraine is no more than two lateral moraines joined together. The derivation of the medial moraine material is therefore essentially the same as the derivation of the lateral moraine material.

It sometimes happens that there are considerable hills in a glacier's bed which the ice is unable to surmount, and it flows around them. Temporarily, an ice stream may be said to be divided into two by each prominence of this sort. These two streams unite below the rock prominence. If the rock prominence be high and steep, it may yield earthy and stony material to the surface of the ice on either hand, just as the slopes above an ordinary alpine glacier give rise to lateral moraine material. Such a boss of rock protruding through the ice may give rise to two lateral moraines, one on either side. These preserve their distinctness around the projecting hill. But where the ice streams on either hand coalesce below the prominence, the two lateral moraines unite and become a medial moraine. In such a case the ice passes over the lower slopes of the prominence which it surrounds. When the ice has closed round such a prominence, healing the wound which it made, some of the material plucked from the slopes of the hill below the surface of the ice, will be found in the ice above its base, that is in englacial position. Some of it may be very near the upper surface of the ice, and some of it will be at lower levels. As the ice passes on down the valley, its surface is subjected to rapid melting. When the uppermost twenty feet of the ice have been melted, all the material which was englacial in this part of the ice will have arrived at the surface, not because it was carried up to the surface, but because the surface was carried down to it. It will be seen that the greater the surface melting, the greater the amount of englacial material which will become superglacial, as the result of ablation. This superglacial material with an englacial history will first make its appearance along the line of the medial moraine which has been formed by the union of the two lateral moraines, since it is the ice along this line which, at the outset, carries englacial material nearest the surface. With surface melting, therefore, the medial moraine composed of superglacial drift and formed by the union of the two lateral moraines, will be augmented by the addition of englacial-superglacial drift. The effect will be to widen the medial moraine, as well as to increase

its total volume, and this effect will be progressive with increasing distance from the hill which was the occasion of the whole phenomenon under consideration.

In many cases there are bosses of rock in the path of a glacier which the ice is able to override. They yield material to the bottom of that part of the ice which passes over them, but it is to be remembered that the bottom of the ice which passes over them may be near the surface of the glacier. When the ice has passed the prominence, the material which was borne from its top may find itself in an englacial position, and may be far above the bottom of the transporting ice. Subsequently, surface melting may bring the surface of the glacier down to its level. Such englacial material then becomes superglacial, and has the general position of a medial moraine. It would be, in fact, a medial moraine made up wholly of englacial-superglacial débris and not produced by the union of lateral moraines.

A lateral or medial moraine is likely to lose its distinctness as the end of the glacier is approached. Where such a moraine has sufficient body, it protects the ice beneath from melting. The ice beneath therefore assumes the form of a ridge, which is drift covered. Under these circumstances, the drift tends to slide down the sides of this ice-ridge. In time the drift may spread itself somewhat widely over a glacier sometimes even covering its whole surface, near its lower end.

The percentage of englacial material which will ultimately become superglacial is believed to depend upon its position in the ice, and upon the relative rates of surface and basal melting. If surface and basal melting be equal, the material of the upper half of the ice will ultimately come to be superglacial. If the rate of melting at the upper surface of the ice be greater than that at the lower, the englacial material carried by something more than the upper half of the ice will ultimately become superglacial, as the result of surface melting.

It is a mooted question whether glacial motion is of such a nature as to allow the transfer of material from the base of a glacier to its surface. It is often urged that drift may be transferred

from a basal to a superficial position, without actually rising. In a mountain glacier, the bed of which is steeply inclined, basal drift would reach the upper surface of the ice if it were carried forward horizontally, or even if its forward path of motion declined at any rate less than that of the bed of the glacier. It has frequently been argued that this is the actual condition of things. While this conception does not involve a rise of material in terms of absolute altitude, it involves the rise of material through the ice which embeds it, or the rise of ice which embeds drift through that which surrounds it. That basal drift may rise through its embedding ice, or that ice embedding drift may rise through other ice in any such way as would be necessary to bring basal drift to the surface, has not been demonstrated. That stony material may be crowded up some slight distance into the ice from below by the help of other material beneath the ice, is readily understood, but in the present state of knowledge there is little warrant for counting upon the rise of material from the bottom of a glacier to its surface. If such rise were a general fact, there should be much more evidence of wear upon superglacial boulders than has yet been found. Indeed, the total absence from most Alpine glaciers of surface boulders showing any trace whatsoever of glaciation, seems to go far toward settling in the negative the question of the rise of basal drift through the ice.

The material which was superglacial at the outset would be likely to remain superglacial to the end, unless it fell into crevasses, or unless some other untoward accident befell it. The englacial-superglacial material must likewise have remained at the surface after once reaching it, unless it suffered some accidental fate.

Broadly speaking, the oldest ice of a glacier is at its lower end. Since the lower end of a glacier has had a longer time than any other part in which to gather superglacial material, and since surface melting has here been greatest, making possible the transfer of more drift from an englacial to a superglacial position at this point than elsewhere, it follows that the lower end of a glacier is likely to have more superglacial drift than any

other part. Wherever it has not, it is because local conditions, such as extensive crevassing, have prevented its retention at the surface.

Superglacial drift of eolian origin.—Another sort of superglacial material sometimes arises through the agency of the wind. As glaciers advance into regions which are free from snow and ice, they advance into regions whence dust and sand may be blown upon them. Once lodged upon the ice, dust is not likely to be carried farther by the wind, since there is sufficient moisture to hold it. Once moistened, too, it is likely to freeze to the surface of the ice. Such dust is liable to removal by superglacial waters. If it escapes them, it is likely to remain upon the ice so long as the latter remains unmelted. It is believed that considerable quantities of dust reach the surface of existing glaciers in this way. Such dust as is blown upon the surface of the ice, within the zone of wastage, is superglacial from the beginning.

This process of dust accumulation goes on most actively near the ends of glaciers, since the surroundings here are best adapted to furnishing the dust. But the same process must go on to some slight extent throughout the whole gathering ground of existing glaciers. As the snow accumulates year by year, it contains a modicum of dust blown upon the snow-field. This dust becomes englacial. The embedding snow is presently converted into ice. As the ice moves toward the end of the glacier, passing from the zone of accumulation to the zone of wastage, its surface melts, and the dust contained in the part which is melted, appears at the surface. Some of it is doubtless washed away by the superglacial drainage resulting from rain and from surface ablation. Such as escapes this fate may remain upon the surface of the ice. The amount of dust which shows itself on the surface of a snow-field at the end of a melting season is sometimes considerable. As seen in section in a snow-field, the snowfalls of successive winters are seen to be clearly defined by the presence of these bands of earthy matter ("dirty ice") between them; these bands indicate the condition in which the surface of

the snow found itself at the close of the successive seasons of melting. A small amount of dust descends from the atmosphere with the snow when it falls. As the snow and ice melt, this is set free, and, in its proper measure, swells the amount of dust which gathers upon the surface in other ways.

Surface melting has been greater at the end of a glacier than at any point above. If it has not been washed away, therefore, the amount of dust which has passed from an englacial to a superglacial position, as the result of surface melting, must be greatest at the end of the glacier. Since the amount of wind-borne superglacial dust which has had no englacial history is also greatest here, it follows that the total amount of superglacial dust which has come through the atmosphere, must be greatest near the ends of glaciers, unless conditions have prevented its preservation. The dust is most likely to remain where the surface of the ice is smoothest, and where there is little surface drainage. Material blown upon the ice is much finer than most of that which descends from the slopes above.

2. PIEDMONT GLACIERS.

Piedmont glaciers owe their origin to the fusion or coalescence of several alpine glaciers. All the material which was on the surface of the alpine glaciers which unite to make a piedmont glacier, will be at the surface of the latter from the beginning. All the englacial material which was carried by the contributing alpine glaciers in their upper parts will become superglacial on the piedmont glacier, so soon as surface melting has brought the surface down to its horizon. Since the only piedmont glaciers concerning which we have knowledge have little motion, surface melting must greatly predominate over basal melting, and the proportion of englacial drift which becomes superglacial must therefore be great. On the Malaspina[1] glacier, which stands as our representative of piedmont glaciers, superglacial drift is most abundant near the edge, where surface ablation has been greatest.

[1] Russell, expedition to Mt. Saint Elias. National Geographical Magazine, vol. III. pp. 53–204, also JOURNAL OF GEOLOGY, vol. I., No. 3, 1893.

At and near the centre, superglacial material is not abundant, because melting has not there been sufficient to carry the surface of the ice below the horizon of abundant englacial detritus. Wind-borne fine material might reach the surface of piedmont glaciers in the same way that it reaches the surface of alpine glaciers.

3. The Continental Ice-Sheets.

1. *Lateral moraines.* Wherever the edge of the continental ice-sheet found itself in a region of strong relief, ice-tongues thrust themselves forward into valleys beyond the main body of the ice. In very many respects such tongues of ice corresponded to alpine glaciers. Upon their surfaces lateral moraines may have accumulated just as in the case of mountain glaciers today. But the country invaded by the continental ice-sheet of North America was, for the most part, not mountainous. Marginal glaciers of the alpine type must have been restricted to those parts of the ice-sheet which invaded mountain regions, or at any rate to areas of marked relief. As the ice-sheet advanced and thickened, it presently covered the elevations which had earlier occasioned the lobation of its edge. So soon as it covered an elevation, this elevation ceased to give immediate origin to lateral moraines. Since on the whole the relief of the country covered by the North American ice-sheet was not great, there was little chance for the development of extensive lateral moraines upon it. While they doubtless existed on the alpine-glacier-like lobes of the ice-sheet's edge in regions of strong relief, they could have existed for considerable distances back from the margin in but few localities. As the ice invaded regions of slight relief, such as the larger part of the Mississippi basin, it could have acquired little superglacial material. No more than miniature lateral moraines could have come into existence. The same conditions which forbade the development of extensive lateral moraines on the continental ice-sheet, gave the ice little opportunity to acquire englacial material which could subsequently become superglacial by surface melting.

As the ice of the continental glacier closed round nunataks, the lateral moraines which had come into existence became medial; but medial moraines, arising by the coalescence of lateral moraines, could not have been more extensive than the latter. After the ice overtopped the nunataks which gave rise to lateral moraines, these same elevations might still yield englacial material to the over-riding ice. Later, part of this englacial material, perhaps became superglacial, by having the surface of the ice brought down to its horizon as the result of surface ablation. On reaching the surface, this material might assume the form of a medial moraine, as in alpine glaciers. As on mountain glaciers, lateral or medial moraines on a continental ice-sheet might readily lose their distinctive character during the melting of the surface ice. As in the case of alpine glaciers, the proportion of englacial material in a continental ice-sheet which must become superglacial as the result of surface melting would depend, 1), upon the position of the englacial material in the ice; and, 2), upon the relative rates of basal and superficial melting. The higher the elevations from which the englacial material was derived, the nearer will it be to the upper surface of the ice at the beginning of its history. The nearer it is to the upper surface of the ice, the better its chance of becoming superglacial. The amount of englacial-superglacial material would therefore be greatest in a region of strong relief, and especially in a country where the relief was great, relative to the thickness of the ice. A region of 2,000 feet relief, beneath an ice-sheet 5,000 feet thick, might yield little englacial material which would ultimately become superglacial. If the ice over the same region were but 2,500 feet thick, a much larger proportion of its englacial drift would be likely to reach the surface of the ice. Since the ice-sheet was always thinnest at its margin, the relief of any given region was always greater, relative to the thickness of the overlying ice, when the marginal part of the ice overlay it, than at any other time. Advance of the ice means the thickening of the ice at all points back of the margin. With increasing thickness of the ice, a less and less proportion of the

englacial material derived from any given elevation would stand a chance of becoming superglacial, because there must be progressively more and more surface-melting, in order to bring the uppermost portion of the englacial material to the surface. Meanwhile basal melting has been going on, and will have brought some of the englacial material to the bottom of the ice, that is, to a subglacial position. Because of its thinness, therefore, the marginal part of the ice-sheet was likely to secure more englacial material capable of becoming superglacial, than any other part.

The ratio of surface melting to basal melting is probably greater at the margin of the ice than elsewhere, so that the upper surface of the ice is here lowered more rapidly than elsewhere. It follows that, as a result of surface melting, a greater proportion of the englacial material acquired by the margin of the ice would be likely to become superglacial, than of that acquired by any other part. Considered from the standpoint of the ice, there are, therefore, two reasons why the marginal part of an ice-sheet should possess more englacial-superglacial drift than any other part.

There is another set of reasons why superglacial material, derived from an englacial source, must be more abundant near the margin of the ice than elsewhere. They relate to the surface over which the ice passes. The passage of glacial ice over a region of rough topography tends to smooth it. It is when the ice first invades a region that its topography is roughest. Later, after the passage of much ice, the rugosities of surface have been reduced, and from the smoother surface the ice is able to get less detritus. Furthermore, quite apart from considerations of topography, it is when the ice first invades a region that there is most loose surface material in a condition to be removed. Later, after longer passage of the ice the materials antecedently loosened by surface agencies have been taken away, and any further acquisition the ice may make must be made from the more solid rock beneath. Considered from the standpoint of the surface over which the ice passed therefore there are two valid rea-

sons for believing that the marginal part of an advancing ice-sheet is more favorably situated for acquiring englacial material than any other. If the marginal part of an advancing ice-sheet acquired more englacial material than any other part, and if a larger proportion of that which it acquired became superglacial, it will be seen that this part of the ice had great advantage over other parts in the matter of superglacial drift. Apart from all considerations of topography, surface material, thinness of ice, and rate of surface melting, an advancing ice margin has an advantage over a receding margin in the acquisition of material, because of its greater vigor of movement.

Not only must englacial-superglacial material be most abundant at and near the margin of the ice, but, under most conditions, it must be more abundant at the margin of an ice-sheet during its earliest advance than at any other time, since it is the first advancing margin which in general finds the roughest topography, and the most loose material ready for removal. A qualification to the first part of this statement, and a partial exception to the last, should be stated. If the interval since the ice has retreated from a given region be long, a rough topography may have been developed since the earlier passage of the ice. In this event, the first advancing margin might have no advantage over the second in securing englacial drift which may become superglacial. When the ice re-advances over a surface from which it has receded, it may find a large supply of loose material in the form of drift, ready for removal.

In summation it may be said that the advancing margin of a continental ice-sheet must have been more abundantly supplied with superglacial material than the receding, because (1) the motion was more vigorous, favoring the acquisition of more englacial material capable of becoming superglacial; (2) the surface over which the advancing margin spread was, on the whole, better supplied with material which might become superglacial, either directly or indirectly; (3) the topography of the country as the ice invaded it, was such as to allow it to acquire material more readily than at any other time. The first of

these conditions applies with equal force to a first or a later ice advance. The second and third apply with greater force to the first advance of the ice, unless the interval between the first and second was sufficiently long to develop a rough and essentially non-glaciated topography. The conditions most favorable for the acquisition of superglacial material are, (1) a rough country, with (2) much loose material upon its surface, affected (3) by an advancing ice margin. Whenever the edge of the ice was stationary, the elevations which were yielding superglacial material, or englacial material which stood a chance of becoming superglacial, were elevations which had already been worked over by the advancing ice, so that they were less productive than when the ice first reached them. When the ice was retreating, its surface would have had still less superglacial material than when stationary.

As noted in connection with alpine glaciers, the drift which has been superglacial from the outset should differ from the englacial-superglacial drift by showing less wear. The difference might be great or slight, depending in part upon the duration of the englacial history of the englacial-superglacial drift.

From what has been said it is clear that the englacial-superglacial drift acquired by the thin margin of an advancing ice-sheet had a shorter englacial history than that acquired by any other part of the ice-sheet. It should, therefore, show less wear than the corresponding drift picked up by the ice back from the margin. The amount of material which was superglacial from the outset must also have been greatest at the margin of the ice during its advance, and this had little or no opportunity of suffering wear. The aggregate of superglacial drift at the margin of an advancing ice-sheet must, therefore, be much more free from wear than that of any part of the ice back from the margin. Since the superglacial drift of a receding ice margin may be mainly or wholly englacial-superglacial, and since it may have been mainly or wholly acquired by ice of considerable thickness, attaining its superior position only after a long englacial course, it follows that the surface drift of an advancing ice

margin must be more free from wear than that of a receding margin.

There must have been another difference between the superglacial drift acquired by an advancing ice margin, and that acquired by other parts of the ice. The advancing margin of an ice-sheet invades territory the surface of which is likely to be provided with the products of decomposition. It is these products of decomposition which in considerable part enter into the composition of the superglacial drift, and into the composition of the englacial drift which is shortly to become superglacial. It follows that the superglacial and englacial-superglacial drift of an advancing ice margin is made up more largely of the products of rock disintegration than the surface drift of any other part of the ice. The drift of a stationary or receding margin constitutes no exception to this general statement, since, as already noted, much of it was originally acquired some distance back from the margin, and from surfaces over which much ice had passed, and from which, therefore, the disintegrated products had been earlier removed.

It should be further noted that it is not merely an advancing ice-sheet, the superglacial drift of which is largely disintegrated and oxidized, but an advancing margin which is invading territory hitherto unglaciated, or unglaciated for a long period of time. During the forward phase of an oscillatory movement, the edge of the ice may be moving over territory which had been but recently abandoned, and which might therefore be free from the products of rock disintegration.

Dust might be blown upon an ice-sheet as upon an alpine glacier, but the thickness which it might attain on the former is far greater than on the latter. The ice of a continental glacier is much thicker than the ice of a mountain glacier. It has been much longer in process of accumulation, and presumably contains more dust. Above the zone of wastage, this is chiefly englacial. In the zone of wastage, it gradually becomes superglacial. Since there is a much longer period of surface melting in an ice-sheet than in a mountain glacier, and so a much greater amount of

surface melting, more dust must finally rest on the surface of an ice-sheet than on the surface of a lesser body of ice. Unless carried away by surface drainage, superglacial material having an eolian origin should appear at the upper (inner) margin of the zone of wastage, and should increase to the very edge of the ice. It should be most abundant in this position, since most ice has here been melted, leaving its dust behind.

To the fine material which was left on the surface by the melting of the upper ice, was added such as blew upon the surface within the zone of wastage, and which was never englacial. Like the former, this latter material must have been most abundant at the extreme edge of the ice.

It is not definitely known how important (quantitatively) wind drift was on the North American ice-sheet. But it is believed that its amount was far greater than has been commonly recognized.

DEPOSITION OF SUPERGLACIAL MATERIAL.

If the margin of an ice-sheet thins to an edge, the englacial drift must ultimately become either superglacial or subglacial. Either basal melting will bring it to the bottom of the ice, or surface melting will bring it to the top. There is no third alternative. If the drift rise or sink through the ice, the case is in no wise altered, so far as the final result is concerned. If an ice-sheet terminates with an abrupt front, it is manifest that some englacial material may be deposited from its englacial position. Since the ice-sheet is believed to have thinned virtually to an edge, it is clear that essentially all the englacial material was either superglacial or subglacial in its final deposition.

While the superglacial drift is being carried forward on the surface of the ice, the edge of the ice is being continually melted back. When it is melted back as rapidly as it advances, the edge of the ice is stationary in position. When the rate of edge melting exceeds that of forward flowage, the edge recedes. When the wastage falls short of the advance, the edge moves forward. In any case the edge of an ice-sheet is being melted

off continually. In the first case, the extreme edge is in the same place from year to year, but the ice which is at the extreme edge this year is not the same ice which was in the corresponding position last year. That ice has been melted. The ice which is now at the edge was then back from the margin the distance of one year's melting. All the drift covering carried by that ice which has been melted during the year has been dropped, and dropped on the surface over which the ice lay when it melted. The superglacial drift on the ice which is now at the front, is the superglacial drift which last year was back from the edge the distance of one year's melting, together with such material as was then englacial, but which surface melting has meantime allowed to become superglacial.

While the edge of the ice remains stationary in position, all deposits of superglacial drift must take place in a narrow belt at its edge. These deposits would tend to build up a marginal ridge, or dump moraine. For reasons already given, a stationary ice margin must have less surface drift than an advancing margin, other conditions being equal.

The case is somewhat altered if the edge of the ice be advancing. If the ice moves forward 500 feet per year, while it is melted back 400 feet, it makes a net advance of 100 feet. But the 400 feet which were at the front last year are gone, and the superglacial material which this 400 feet of ice carried has been deposited where the ice which carried it melted, that is, *on ground now occupied by the ice*. The ice has already worked over in part, and buried in part, the superglacial material deposited from the 400 feet of ice which have been melted off during the year. When the ice has advanced still further, it will have covered the particular superglacial drift referred to more deeply, and will have modified it more completely. At no considerable distance from the margin, the larger part of it would probably have lost every trace of its earlier superglacial character, by having been worked over beneath the ice, and so converted into subglacial drift. Such part as did not suffer this fate might be buried, and, in genesis, would be *superglacial material* (super-

glacial till). In position it would be *beneath the subglacial drift deposited by the same ice-sheet.*

At every stage in the advance of the ice-sheet, there would be a narrow margin of ice covering the superglacial deposits made at the edge of the ice just before. Such superglacial deposits might for a time retain their superglacial characteristics, even though buried by the ice. So long as this remained true, their classification might be open to question. But it is not apprehended that this condition of things commonly existed for any considerable distance back from the ice's edge. This statement, which is believed to be true as a general statement, is not to be construed to mean that superglacial material, deposited by an advancing ice-sheet, may not in exceptional cases be buried by the subglacial deposits of the ice at a later and more advanced stage of its development, without being in any way changed, beyond being compacted by the pressure of the over-riding ice.

The ice at any stage whatsoever in the period of its advance, must have worked over, or in exceptional cases buried, all the superglacial material which had been deposited up to that time. What had been superglacial material thus became subglacial, as the ice advanced. However great the amount of superglacial material acquired and deposited by the advancing edge of a continental ice-sheet as it passes over rough surfaces, essentially all of it must subsequently be reworked beneath the ice, must lose its superglacial characteristics in the process, and must have impressed upon it the features which ice impresses upon materials worked over beneath itself. That is, all superglacial and englacial-superglacial drift deposited by an advancing ice-sheet must be transformed later from superglacial into subglacial drift. It has already been shown that it is the advancing margin of an ice-sheet which is most favorably circumstanced for carrying a heavy load of superglacial material. The conditions of glacier motion and melting determine the continuous deposition of this material, while the ice is still advancing. It follows that the heaviest deposits of superglacial material which an ice-sheet can make at any period of its history, cannot retain their super-

glacial character, but are necessarily converted into subglacial drift.[1]

Such superglacial drift as was deposited by the melting of the ice at the time of its maximum extension, and later, after the recession began, would not become subglacial except by a subsequent advance of the ice. But oscillations of the ice-edge are probably frequent, even during the recession of a continental glacier, and it is only the superglacial drift left by the ice in any given locality at the time of its final withdrawal from that locality, which can properly be classed as superglacial drift. In view of this fact, and in view of the further fact that receding ice has little superglacial drift to deposit, it would seem that there was little chance for the presence of much superglacial drift in such a region as that from which our continental ice-sheet withdrew, unless, indeed, there was actual transfer of drift from a basal to a superglacial position. Not only would the amount of superglacial drift deposited by the receding ice be slight, compared with the deposits of an advanced or advancing margin, but it would be composed of fresher material, which had been subjected to more wear. It would, therefore, be less distinct from the subglacial drift, so far as these characteristics are concerned, than the superglacial drift deposited by the extreme margin of the ice.

It is no part of the purpose of this paper to discuss the criteria for the recognition of superglacial drift in glaciated regions. This may be the subject of a later paper. But it may not be useless to point out that such superglacial material as was deposited by the ice at and near the limit of its maximum advance, may have been largely acquired by the advancing margin of the ice while working over territory which had not been glaciated hitherto. So far forth, it may have been largely composed of oxidized, and disintegrated materials. Here, and here only, it is

[1] This statement leaves out of consideration the effect of possible unequal rates of advance and recession of the ice. Such inequality might slightly change the result. It also leaves out of consideration the drift which is thought by some to rise through the ice during its motion.

conceived, was the superglacial drift notably more oxidized and disintegrated than the subglacial at the time of its deposition. It is not believed that this belt of notably oxidized and disintegrated superglacial drift could have been many miles in width, even when the ice-sheet with which it was connected was wide. Toward the direction whence the ice came, the character here noted would gradually disappear.

ROLLIN D. SALISBURY.